

# Space Medicine





## **Disclosure Statement**

- The presenter has no financial affiliations to disclose.
- The presenter does not discuss off label use or investigational use in the presentation.

A vertical strip on the left side of the slide shows a close-up view of the International Space Station (ISS) orbiting Earth. The station's complex structure, including solar panel arrays and various modules, is visible against the bright blue and white of the planet's surface and atmosphere.

# Overview

- Human physiology in microgravity
- Medical and laboratory support
- Astronaut training
- Need for new medical sensors and biomarker technologies
- One year ISS mission



# Learning Objectives

At the conclusion of this lecture, the audience might:

- Understand a little of microgravity's effect in the space flight environment
- Recognize the redistribution of body fluids on human physiology in space flight
- Identify effects of long-duration space flight on the human body

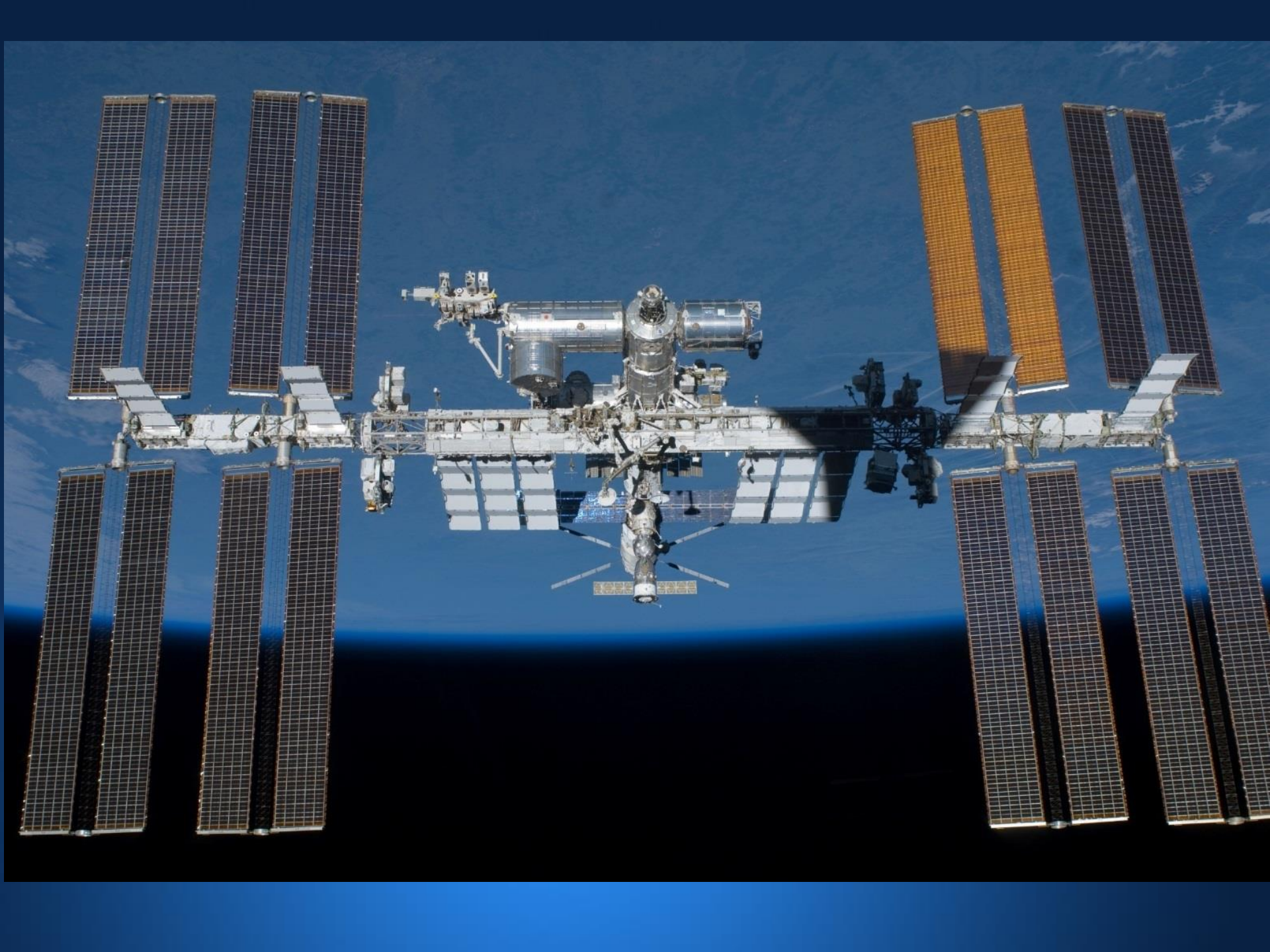












# Space Medicine

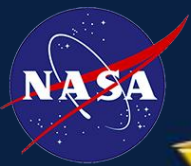


- Healthy individuals in extreme environments
- Monitor and maintain the health of astronauts throughout their careers
- Support crews with the stressors of space flight



A detailed illustration of the International Space Station (ISS) in orbit above the Earth. The station's complex structure, including multiple modules, trusses, and large solar panel arrays, is clearly visible. The Earth's blue and white surface is seen below, while the black void of space with distant stars is above. A yellow banner is overlaid on the right side of the image.

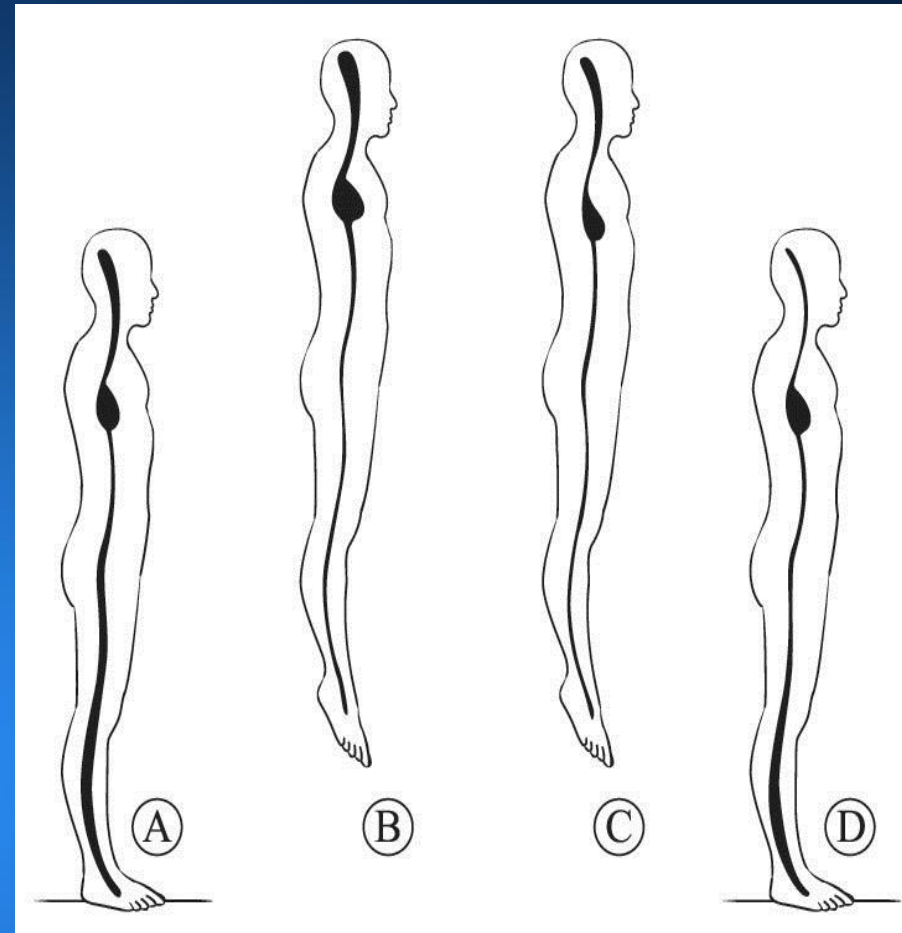
# **Physiological Changes of Spaceflight**



# Rapid Effects--Fluid Shift

**Acute physiological changes due to redistribution of body fluids towards the head**

- On Earth, gravity exerts a downward force to keep fluids flowing to the lower body (A).
- In space, fluids redistribute toward the chest and upper body (B).
- The body undergoes rapid volume contraction. The body functions with a smaller plasma volume (C).
- Upon return to Earth, gravity again pulls the fluids downward, but there are insufficient fluids to function normally on Earth (D).





## Fluid Shift



- Fluids make headward shift
  - Head fullness
  - Decreased thirst and oral fluid intake
  - Nasal congestion
- Volume contraction by 1-2 L
  - Intracellular fluid shift
  - No diuresis
- Appearance: Puffy face - Bird legs







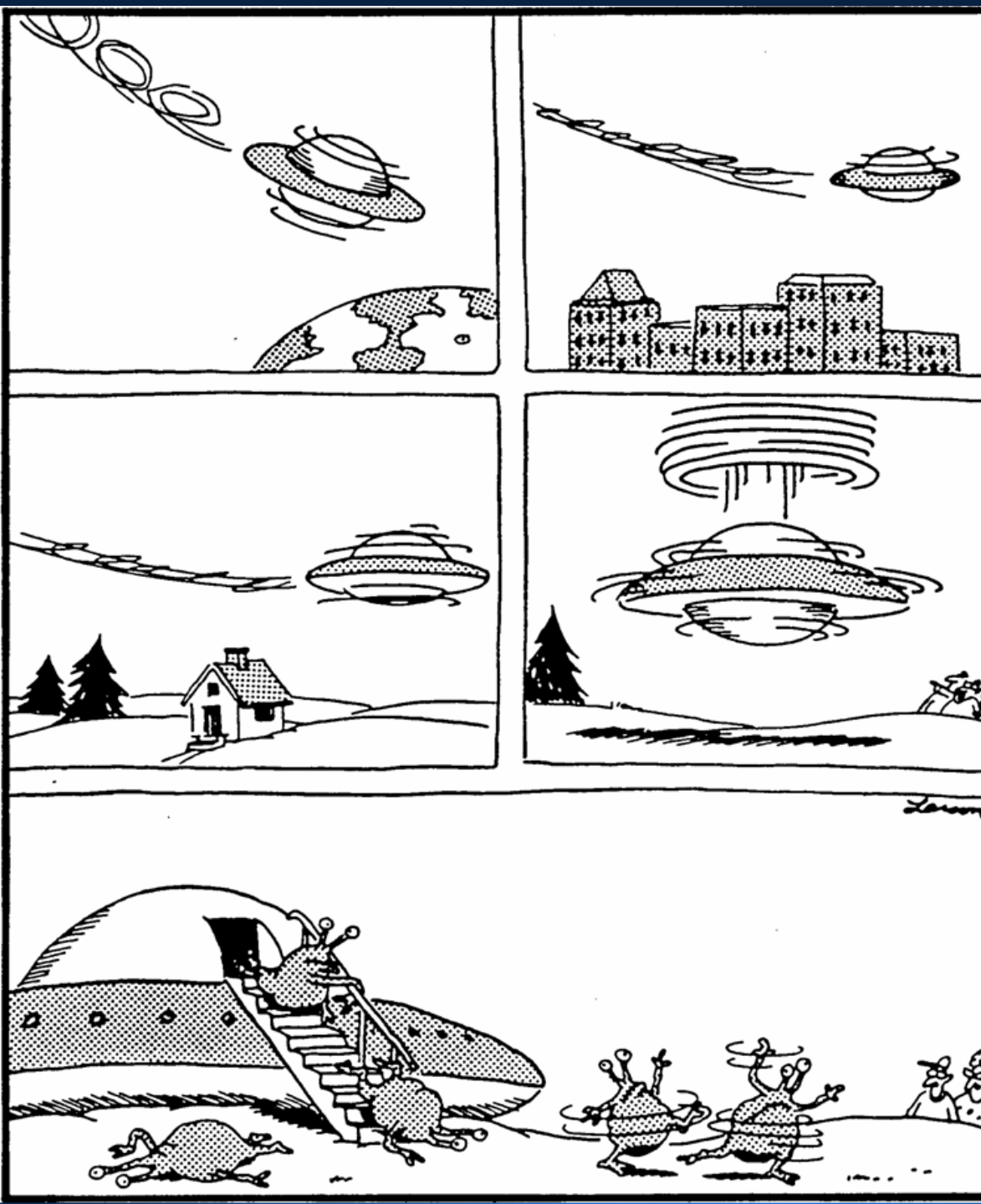
## Physiological Changes in Space--Hematology

### Hematologic effects--**normal adaptation to microgravity:**

- **After Launch**
  - Cephalad fluid shift
  - Volume contraction
  - Erythropoietin and RBC production decline
  - Red cell mass reduced 10%, with return to normal Hct
  - Plateau after first weeks of space flight
- **Upon Landing**
  - Normal plasma volume within 24-48 hours
  - Dilutional "Space Flight Anemia" short term
  - Increased RBC production returning both Hct and red cell mass to normal over several weeks







# Space Adaptation Syndrome

**Primarily problematic for the first 2-3 days and upon earth return for 48-72 hours**

- Incidence - All crewmembers affected to some degree
- Symptoms
  - Headache and lethargy
  - Sensitivity to motion
  - Diminished appetite and stomach awareness
  - Nausea and vomiting



# Neurovestibular Effects

## **Initial adaptation to microgravity: Lack of gravitational cues**

- Mismatch between eyes and other sense organs
- Visual and perceptual illusions
- Rapid adaptation to permit fine motor control

## **Post-landing: clinically significant neurologic impairments**

- Neurosensory control of motor activities disrupted
  - Postural instability and loss of coordination
  - Clumsiness in movement
  - Difficulty walking a straight line
- Vertigo
- Perceptual illusions: illusory self-motion

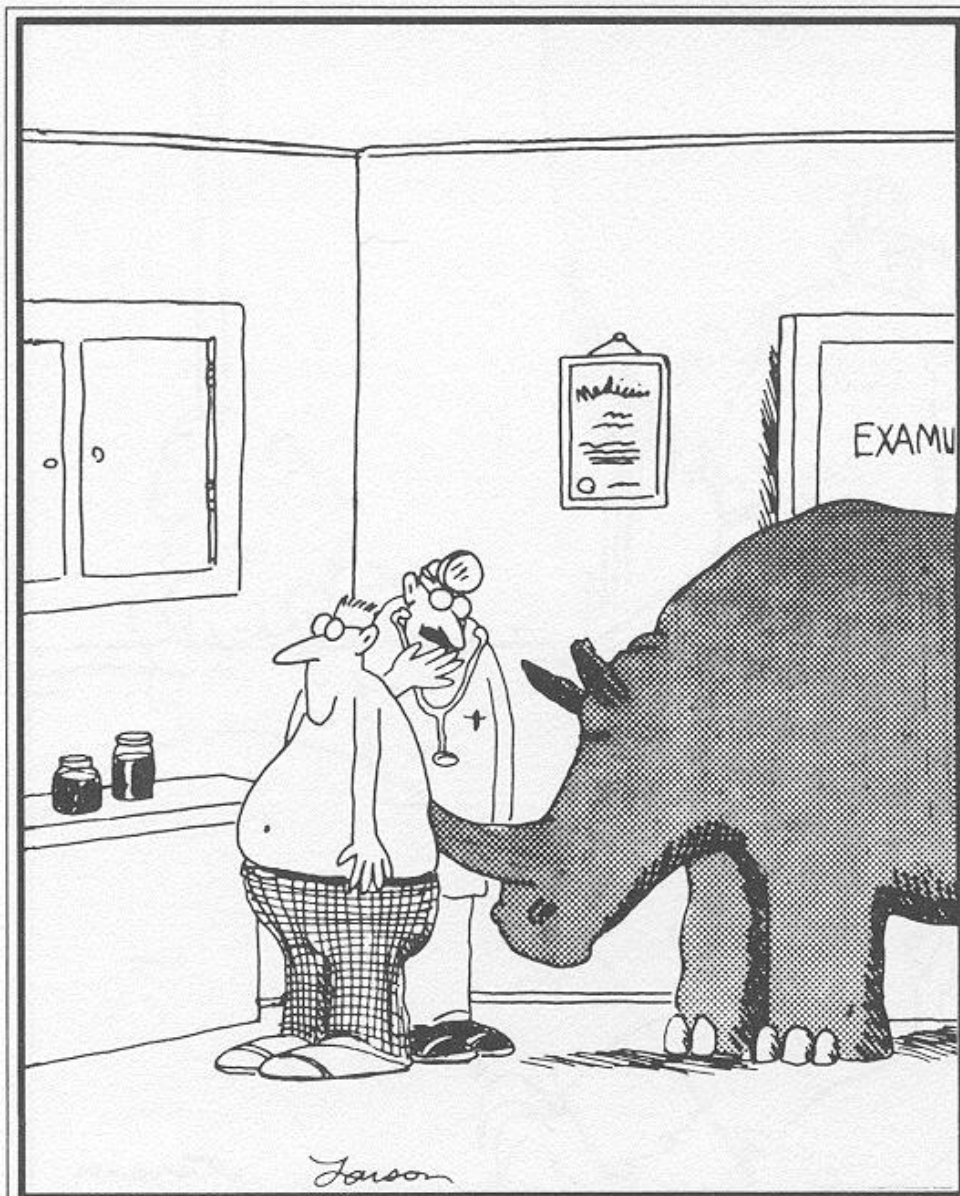
## **Functional assessment tasks**

- Balance control, ambulation, and eye-head coordination tasks
- Aid in decision to return to terrestrial activities



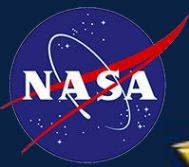
# Calcium Metabolism

- Kidney Stone Risk Factors
  - Microgravity
  - Dehydration
  - Altered bone metabolism
  - Increased urine and fecal calcium excretion
- Kidney stones reported following short- and long-duration space flight



"Wait a minute here, Mr. Crumbley . . . Maybe it isn't kidney stones after all."

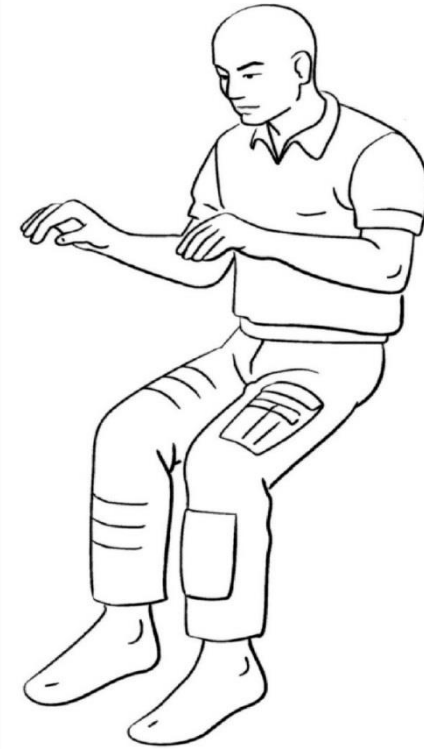
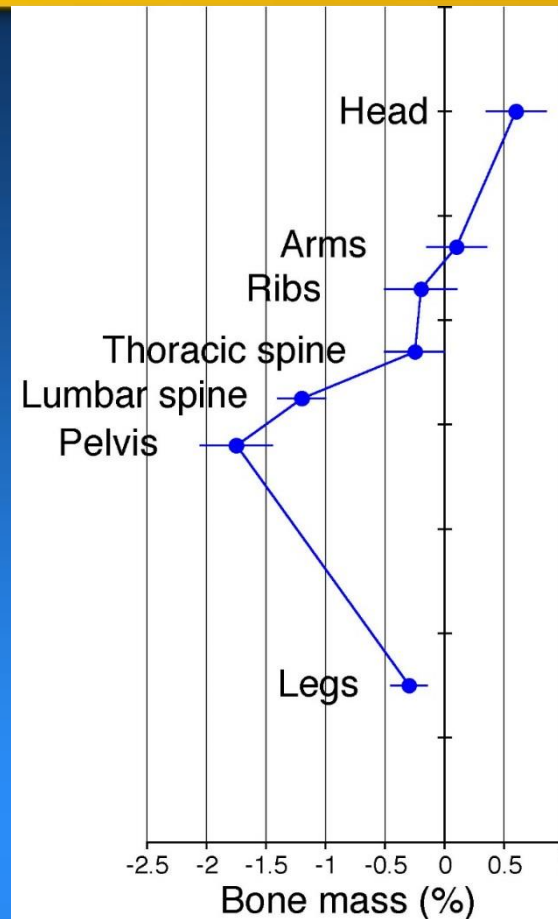


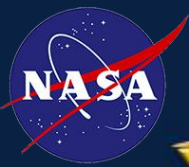


# Bone Loss during Spaceflight

Bone Loss – typically 1-2% per month

- Major areas: femoral neck, greater trochanter, spine
- Recovery process lengthy
- Risk of fragility fracture long-term concern
- DXA scans for changes in bone mineral density
- Bisphosphonates an effective countermeasure to maintain bone density
- Better hardware for resistive exercise and treadmill decreasing bone loss on ISS

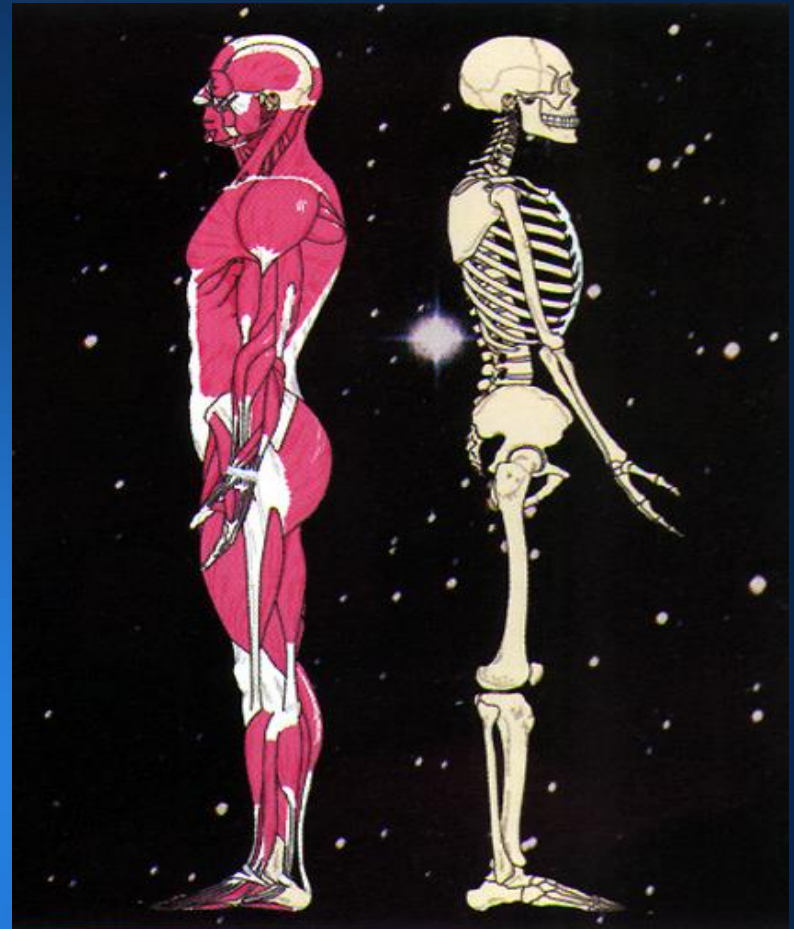




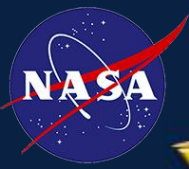
# Effects of Spaceflight on Muscle

## Normal adaptation to microgravity:

- Absence of gravitational loading on bones and muscles
- Decrease in mass and strength
- Atrophy of the postural muscles that maintain our bodies upright in a gravitational environment (thigh, calf, lumbar muscles)
- Straightening of natural spinal curve
- Back pain







# Exercise as Countermeasure



A photograph of a space station module, likely the International Space Station, in orbit against a blue background. The module is white with various equipment and solar panels.

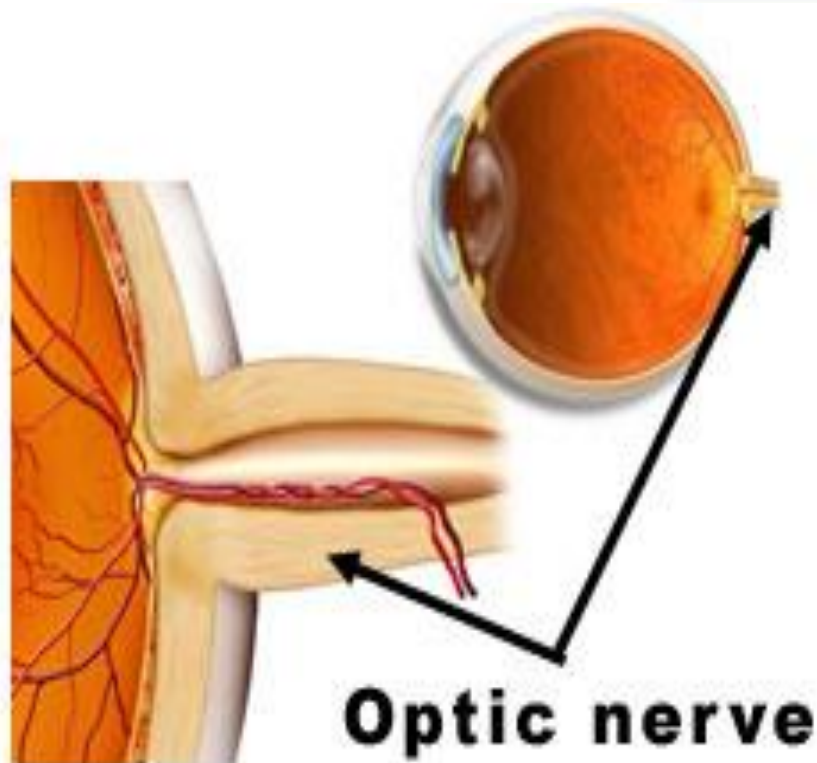
## Physiology in Space-Immune System

- Quarantine program pre-launch
- **Depression of lymphocyte T-cell function affecting at least 50% of space crew members**
  - Mostly subclinical
  - Lack of normal activation of T cells
  - Humoral responses not affected
- **Adaptive immunosuppression during flight may be due to:**
  - Physiological stress
  - Circadian misalignment
  - Isolation and confinement
  - Space radiation
- **Gradual improvement in immunity over days to weeks post-flight**





# Vision Impairment Intracranial Pressure (VIIP)



- **Visual Changes**
  - Changes in visual acuity
  - Optic disc edema
  - Papilledema
- **Headache**
- **Elevated CSF pressure**
- **Potential causes:** fluid shift, microgravity,  $\text{ppCO}_2$
- **Mitigation strategies**
  - Maintain  $\text{ppCO}_2$  on ISS  $< 3.0$
  - MRI 3.0 Tesla pre- and post-flight with eye coils
  - In-flight monitoring
- **Changes not always reversible**









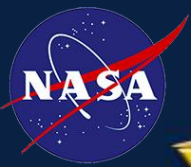




## Physiology in Space-Microbiology

- **Microorganisms inevitable travelers with humans into space**
  - Estimated 10-times more microbial cells than human cells in our bodies (several pounds)
  - Enhanced bacterial cell growth during spaceflight: *Salmonella enterica*, *Escherichia coli*, and *Bacillus subtilis*
  - Increased bacterial virulence
- **Latent virus reactivation**
  - More frequent reactivation of Herpes viruses in astronauts (EBV, CMV, VZV, HSV)
  - Thought to be due, in part, to the uniquely stressful environment of spaceflight
- **Microbiome research ongoing**





# ISS Environmental Monitoring



**Microbial Air Sampler**

- **Pre-flight**
  - Microbial analyses of consumables (water and foods)
  - MRSA and H Pylori screening of crewmembers
- **In-flight**
  - Air and potable water quality
  - Cleanliness of surfaces
  - Radiation hardware
  - Space weather
  - Acoustics (Noise levels)

Biosafety Review Board of all scientific payloads containing biohazardous materials for appropriate levels of bio-containment



A photograph of a space shuttle in orbit, showing the main body and large solar panel arrays against a blue background.

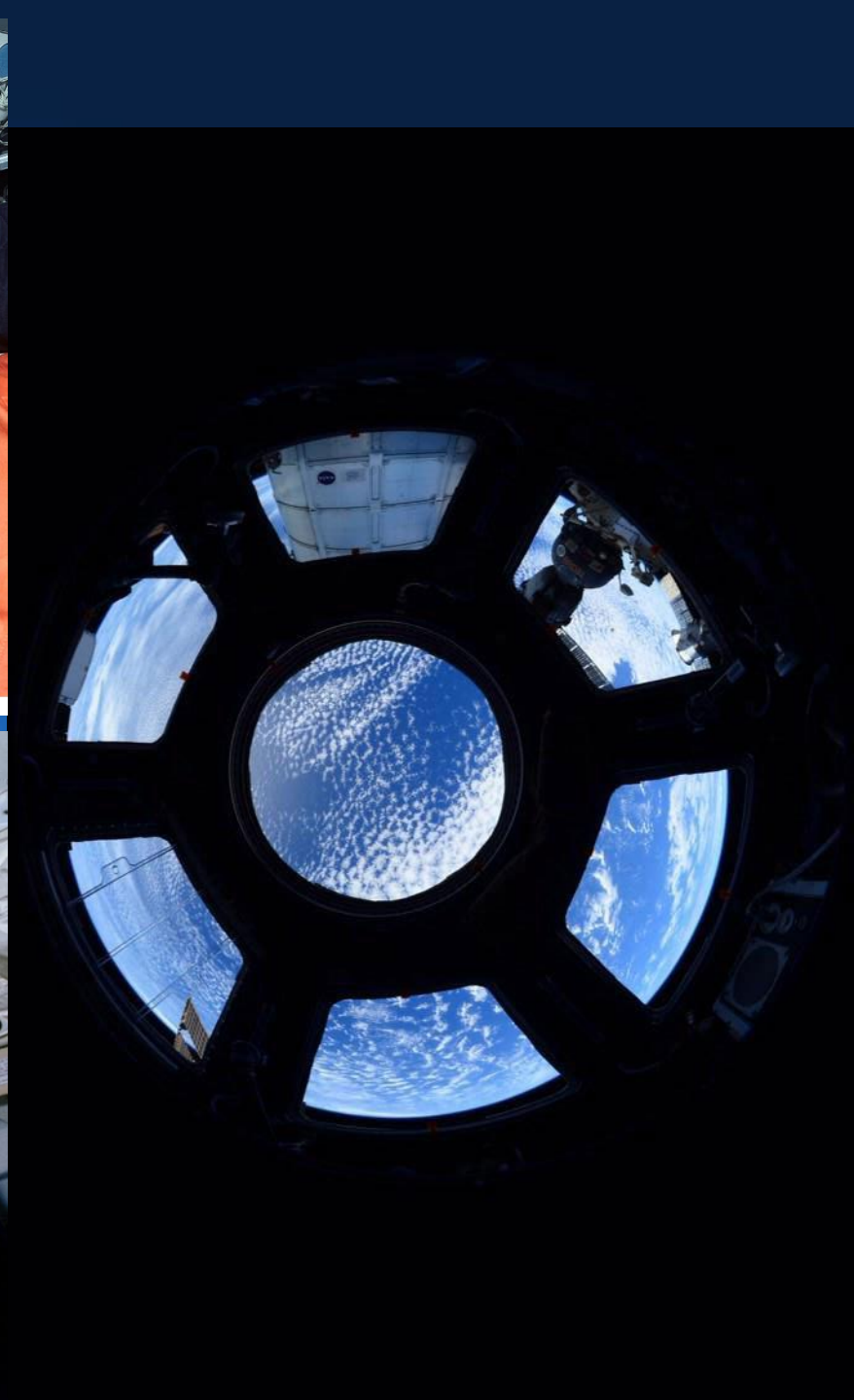
# Space Flight Environment

## **Hazards to the human unique and not well understood:**

- Microgravity
- Closed-loop Environment with a Man-made Atmosphere
  - Long-term exposure to elevated CO<sub>2</sub>
  - Iodine as microbial disinfectant in spacecraft water system
- Isolation and confinement
- Space Radiation--charged particles, electromagnetic radiation, galactic cosmic rays
- Toxicological Risks in Spacecraft
  - Ammonia and ethylene glycol
  - Offgassed products (formaldehyde)
  - Batteries (electrolytes and fire hazards)
- Vibration and Noise



S109E5937





A detailed 3D rendering of the International Space Station (ISS) in orbit above Earth. The station's complex structure, including multiple modules, a large truss system, and extensive solar panel arrays, is clearly visible. The Earth's blue and white surface is seen below, while the black void of space with distant stars is above. A yellow banner is overlaid on the right side of the image.

# **Medical and Laboratory Support for Human Space Missions**



## **Space Medicine Responsibilities**

- Provide comprehensive medical and behavioral health care for active astronauts
- Conduct astronaut selection screening
- Provide routine pre-, in-, post-flight care
- Review and monitor research participation
- Oversee astronaut training
  - Medical procedures
  - Space physiology
  - Teamwork, leadership, cross-cultural training
- Conduct astronaut occupational surveillance for astronaut retirees



A vertical strip on the left side of the slide shows the Space Shuttle Columbia in orbit above Earth's cloud-covered surface. The shuttle is oriented vertically, with its nose pointing upwards. The background of the slide is a solid dark blue.

# Clinical Laboratory Support

- Provide comprehensive laboratory testing for astronaut selection and recertification
- Participate in expert panel reviews of laboratory test profiles and other ancillary testing
- Identify diseases or predilection for diseases, which might compromise individual health or mission safety



# Shuttle Astronaut Selection Laboratory Testing

- **Blood work-up**
  - **Hematology** - Complete blood count, PT, PTT
  - **Biochemical screen** – Urea, creatinine, uric acid, AST, ALT, GGT, ALP, bilirubin, TSH, total cholesterol, HDL, LDL, triglycerides, HS-CRP, electrolytes (Na, K, Cl), calcium, magnesium, inorganic phosphate, fasting blood glucose, HgA-1-C, prostate specific antigen (males, over age 40)
  - **Immunology**
  - **Serology**
  - **Endocrinology**
  - **Pregnancy test**
- **Urinalysis**
  - 24-h urine chemistry
  - Renal-stone profile
  - Endocrinology
- **Stool analysis**
  - Occult blood
  - Ova and parasites
- **Infectious Disease Screen**
  - Syphilis screen – VDRL or RPR or equivalent
  - HIV screen
  - Hepatitis screen for A, B, C exposure and immunity
  - Tuberculin test (PPD)
- **Drug screening**





ISS022E014319



## **Pre-flight and In-flight Care for Long-Duration ISS Crew**

- **Pre-flight Medical Screening**

- Resolves any medical conditions that could interfere with a successful mission
- NASA Aerospace Medicine Board review of astronaut record to ensure medical requirements are met
- All crews approved for flight by an international medical board composed of space medicine specialists from agencies participating in the ISS

- **In-flight Medical Care**

- Dedicated flight surgeons and behavioral health teams for each mission
- Medical capabilities and in-flight diagnosis constrained due to challenges associated with deploying clinical instrumentation to space



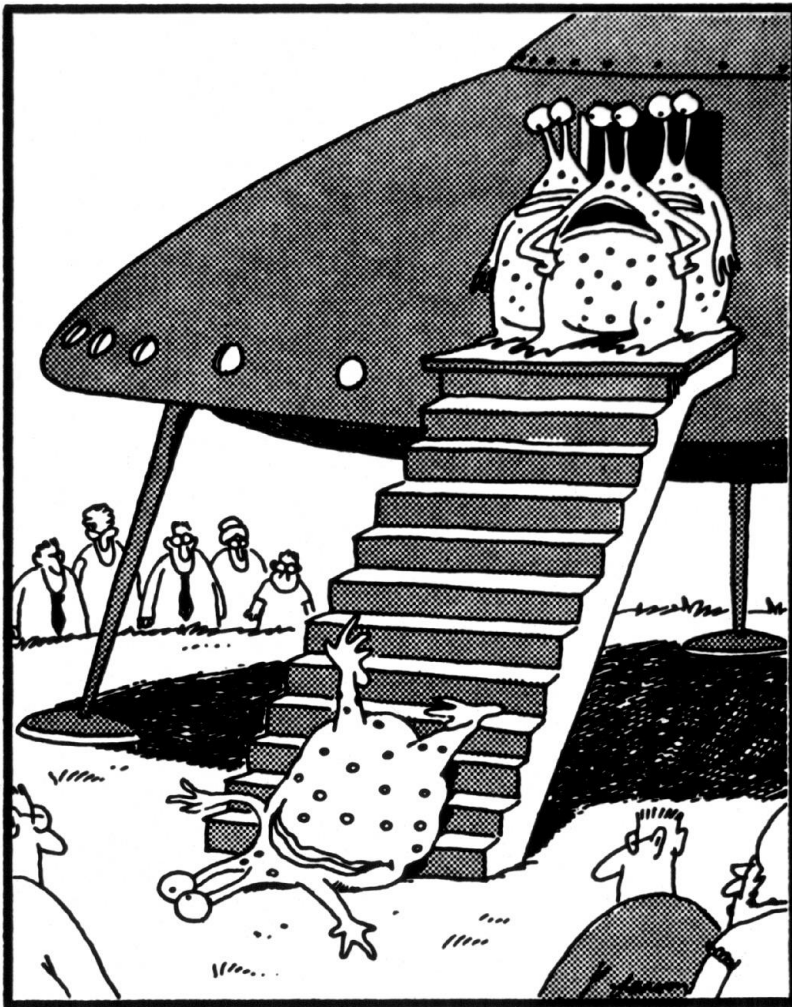












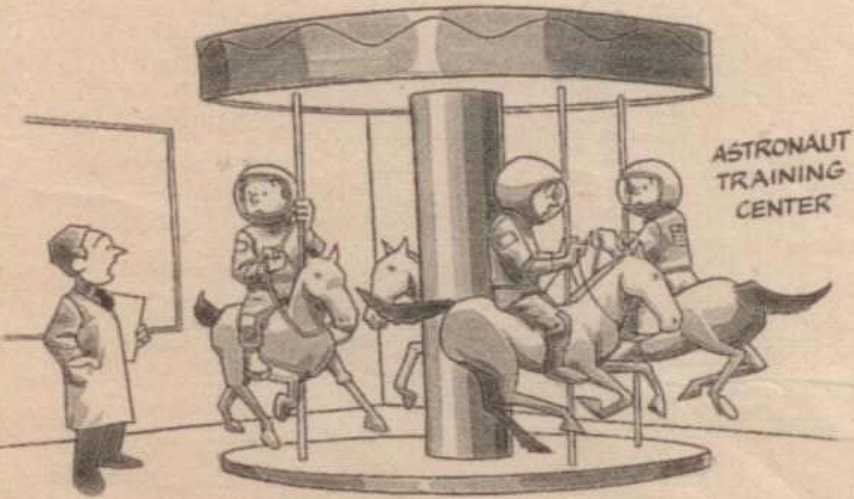
"Wonderful! Just wonderful!... So much for instilling them with a sense of awe."

## Post-flight Medical Care

- **Post-flight medical care**
  - Address acute medical issues
  - Implement rehabilitation plan
  - Long term monitoring and follow-up
- **Recovery may be longer than the mission itself**
- **Blood volume limits**
  - Landing day: 120 ml
  - R+1 to R+45 days = 300 ml
  - 6 month in-flight blood volume = 450 ml

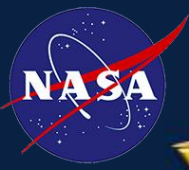


# Training



"Okay, men, we're going to start you off easy."





# Desert Survival Training







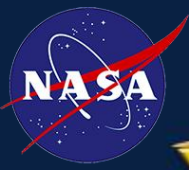




## Reduced Gravity Aircraft “Vomit Comet”



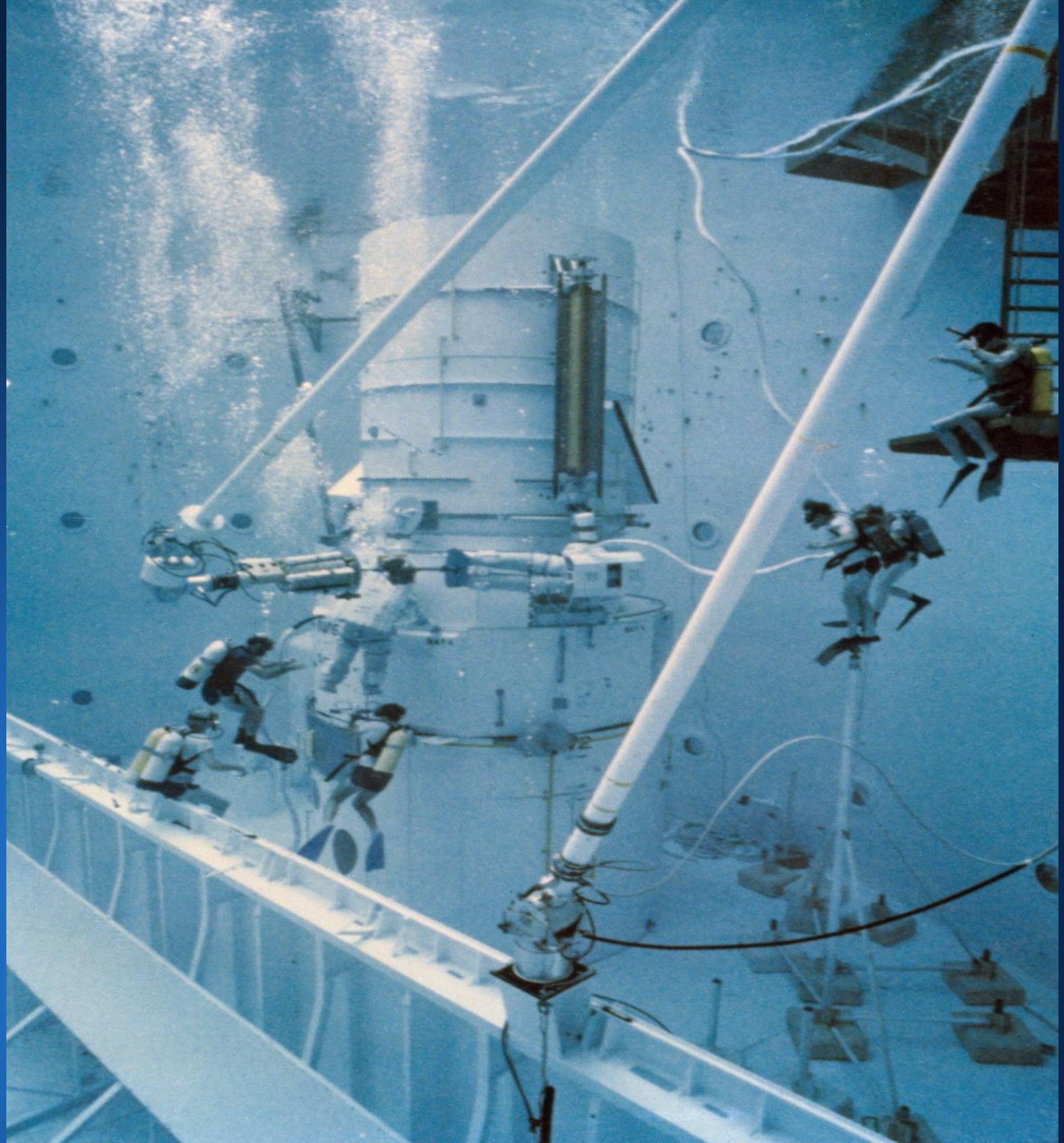




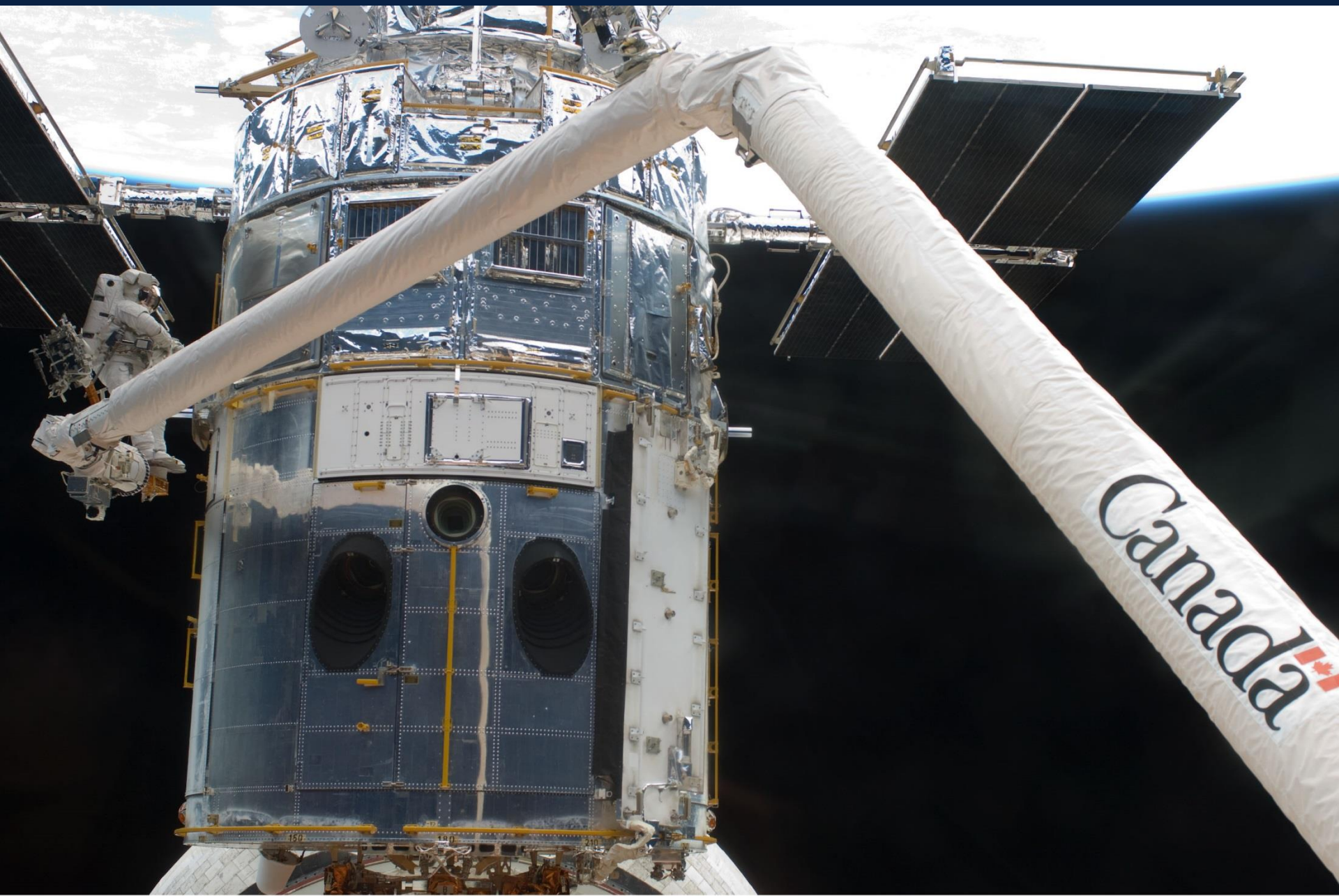
# Neutral Buoyancy Laboratory











S125E007170













ISS013E86739





## Medical Instrumentation Onboard ISS

Current diagnostic capabilities limited:

- Blood collection supplies
- Urinalysis strips
- Working fixed-angle centrifuge
- -80 degree C freezer
- Portable ultrasound
- Vision instrumentation
- Glove box





ISS014E17531





ISS026E024508



# MELFI= Minus Eighty-degree Laboratory Freezer for ISS







## NASA Biological Specimen Repository

- Planned for future human space flight related research
- Repository to be opened to solicitation from investigators following the end of the ISS in 2024
- All participating agencies will be represented on the Advisory Committee and will review the protocols and specify the conditions under which data and specimens may be released and shared (JSC, ESA, JAXA and CSA).

## Bringing Samples Home

### Space Shuttle

- Clinical Lab supported all landings in Florida and California
- 2011 retirement eliminated ISS sample return



### SpaceX

- Began 2012
- 6 successful launches
- Provides sample return from ISS to Earth for analyses







## NASA's Deep Space Missions— Desired Analyzer

- **On-orbit sample analysis**
- **Single compact device** for multiple sample types and multiple analytes
- **Mobile device technology**
  - **Medical add-ons for smart phones**
  - **Cameras and video recorders**
  - **Sensor technologies**—measure vital signs, such as temperature, heart and respiration rates
  - **Non-invasive specimens** (breath and saliva)
  - **Intuitive Interfaces** to accommodate the skill and medical training of crew



## New Laboratory Hardware Specifications

### Minimize:

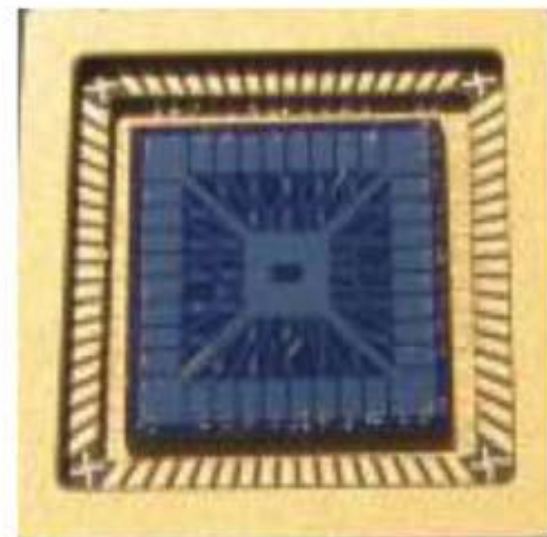
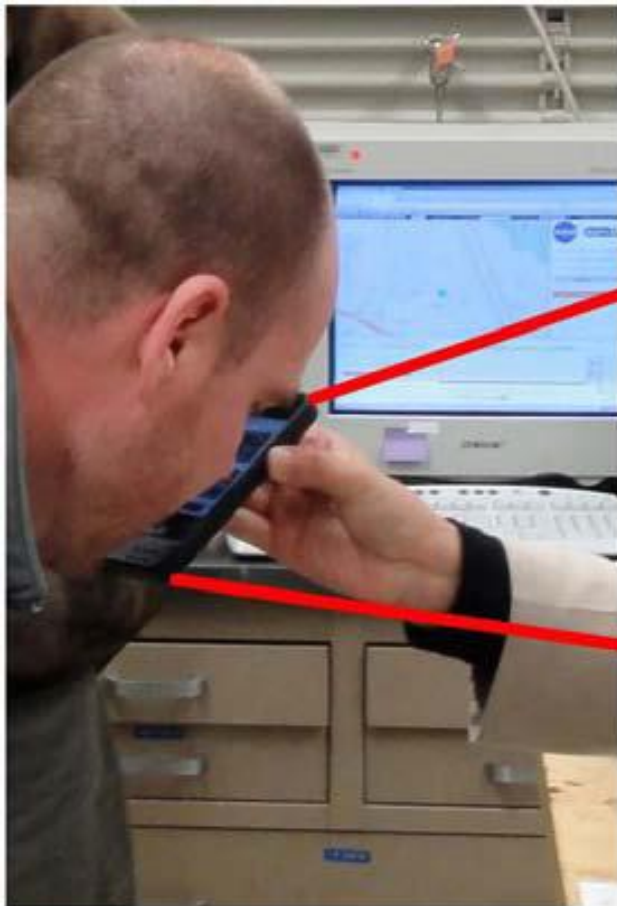
- Size
- Power requirements
- Moving parts
- Use of liquid reagents
- Liquid biohazardous waste
- Time required for sample pre-processing
- Start-up time
- Refrigerated storage
- Hardware certification for spaceflight

### Maximize:

- Ease of operation—minimal training
- Intuitive user interface
- Rapid analysis
- Room temp shelf-life stability of reagents and supplies for prolonged periods of time (goal 3-5 years)
- Expansion of analyzer's capability over time (through software, reagents)
- Ruggedness and vibration tolerance
- Achievement of FDA approval or equivalent

**Overcome limitations of current portable POC devices – all ill-suited for space travelers on extended missions**





# Breath Analysis

**NASA Ames Smart-phone integrated  
Carbon Nanotube Array Sensor**



## **X Prize Foundation: Incentivized Prizes**

### **\$10M Qualcomm Tricorder XPRIZE**

- Single portable device weighing no more than 5# (2.3 kg)
- Ability to diagnose more than a dozen medical conditions
- 7 finalists, with winner to be announced in early 2016

### **\$2.25M Nokia Sensing XCHALLENGE**

- Address resource scarcity in third world economies
- Miniaturized hardware sensors and software sensors
- Improved test methods and new alternatives to blood testing, heart monitoring, and imaging
- 2 competitions thus far: 2 grand-prize winners and 10 distinguished awards

**FDA offering regulatory input to the competing teams**

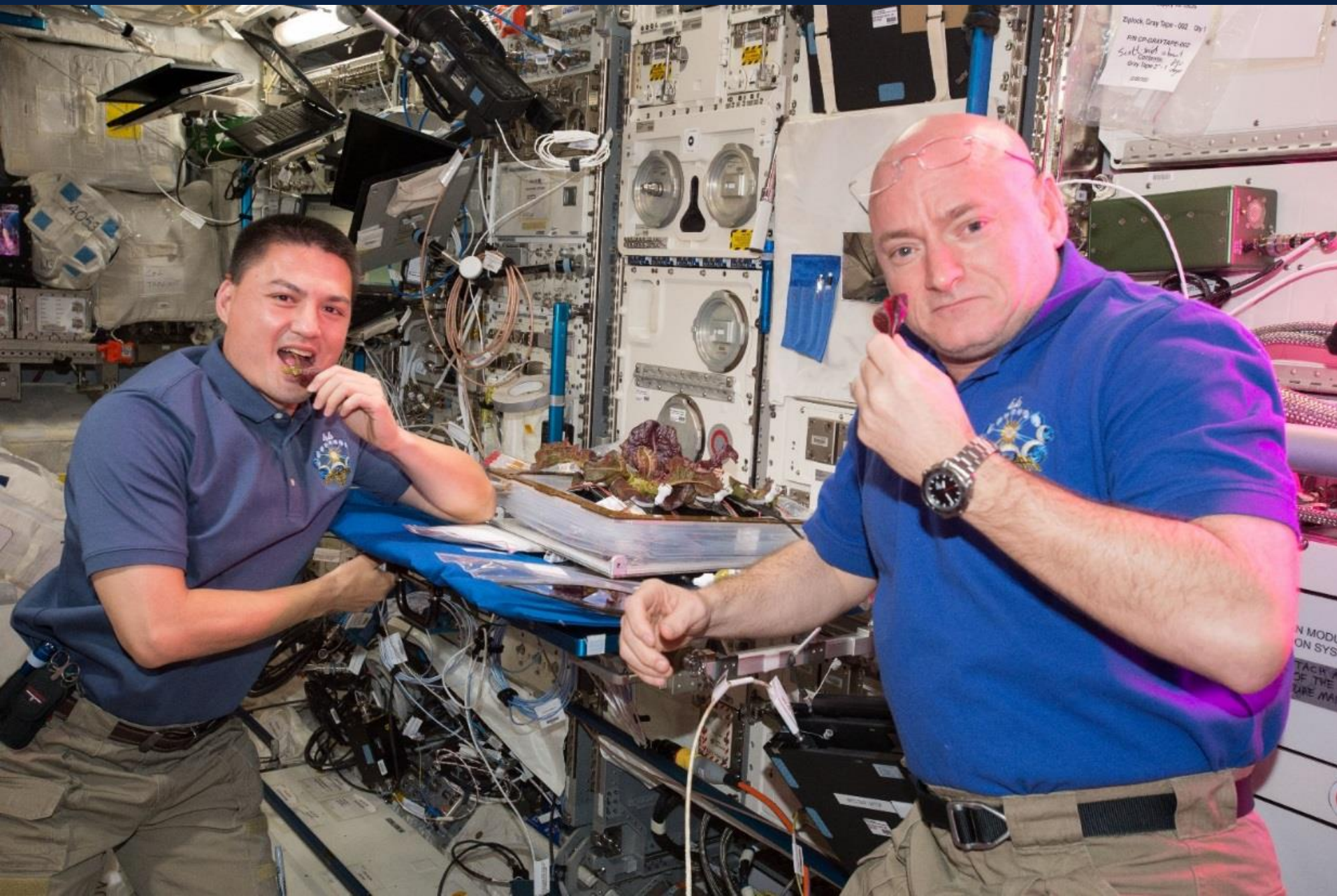




# One-Year Mission







Ziplock Bag Type - 002 Day 1  
for CP-001/002-002  
S-1, S-2, S-3, S-4  
Dry Bag 2 - 1/2

N MODU  
ON SYS  
TACK  
OF THE  
URE MA



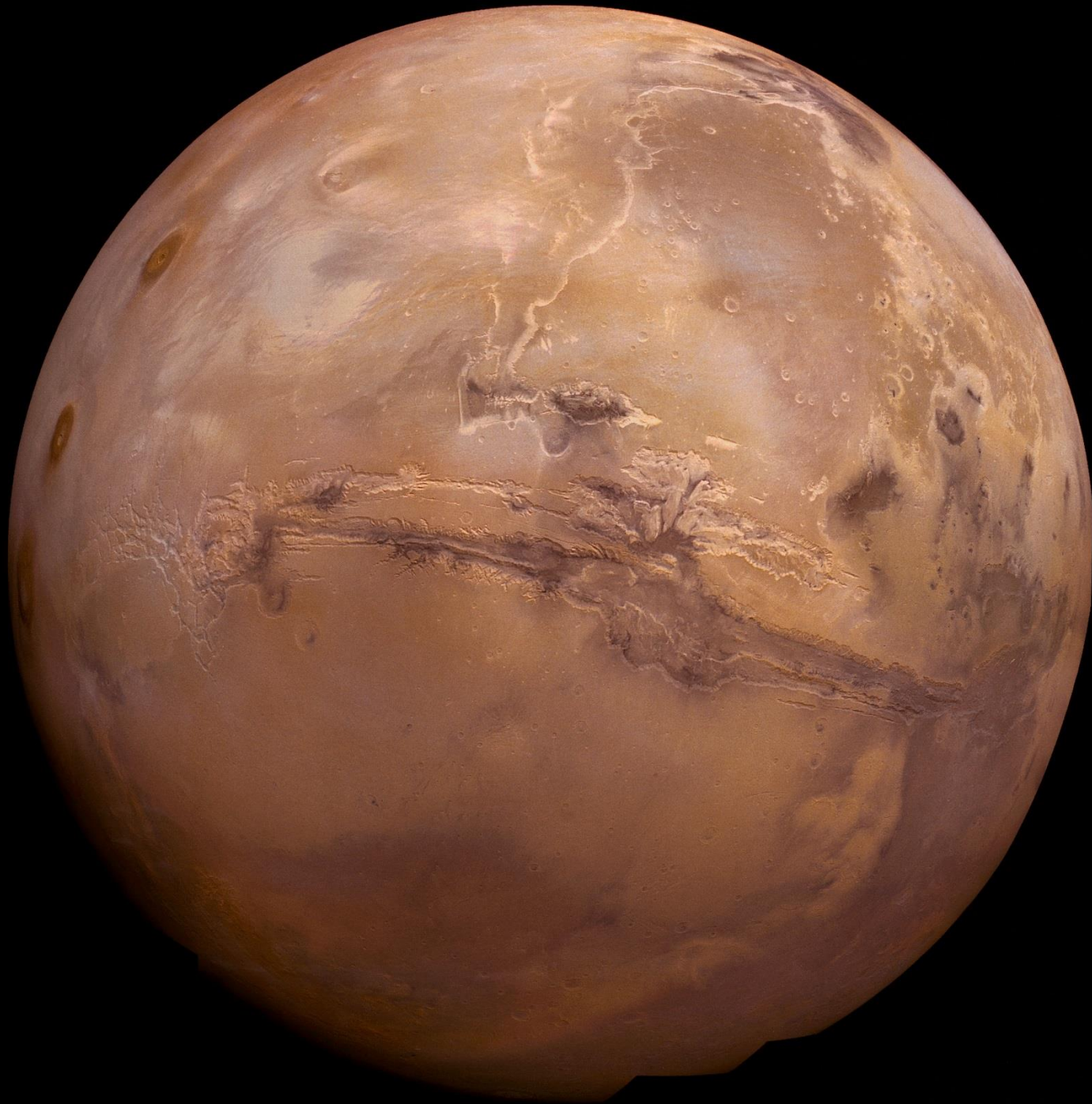


A vertical strip on the left side of the slide shows the Space Shuttle Columbia in orbit. The shuttle is white with black and blue markings, and its large solar panel arrays are extended. Below the shuttle, the Earth's surface is visible, showing blue oceans and white clouds. The background of the slide is a solid dark blue.

## One-Year Missions

- Need to know much more about human reaction to long-term spaceflight before any deeper exploratory missions can be planned
- Remarkable similarities between how the body changes in microgravity and how it changes as a result of ordinary aging
- By learning more about one, we hope to apply that same knowledge toward arresting both conditions











**YOU ARE HERE**



**Kathleen McMonigal MD**  
**Johnson Space Center**  
**2101 NASA Parkway, Mail Code SD**  
**Houston, TX 77058**  
**281-244-5004**  
[kathleen.a.mcmonigal@nasa.gov](mailto:kathleen.a.mcmonigal@nasa.gov)